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EXPLOSIVELY ACTUATED FAST-OPENING SWITCHES FOR VERY LARGE CURRE--ETC(U)
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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EXPLOSIVELY ACTUATED FAST-OPENING SWITCHES FOR VERY LARGE CURRENTS*

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ABSTRACT

In a series of eight experiments we investigated the use of high explosives to interrupt electric current by fast-opening switch mechanisms. The conducting link in seven of the experiments was a glass-lined plasma-filled cavity that was closed explosively. In the eighth experiment a foam-metal link was driven into the liquid-vapor phase and expanded into a ceramic cavity. Resistance increases and resultant voltage spikes that corresponded in time with the particle velocities of the collapsing walls were obtained. However, unknown high-resistance paths prevented voltage gradients greater than 10^5-10^6 V/m.

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Introduction

Ongoing programs at ERDA laboratories will require the interruption of large (i.e., tens of MA) currents in periods of a few microseconds or less. This mechanization, known as an "opening switch" or "fuze," produces high voltage drops. For instance, an inductive voltage drop of 10^7 V is required to interrupt 10^8 A through an inductance of 0.1 μH in 1 μs.

The most commonly used opening switch is a fusible link of exploding bridgewires or foil in parallel with the load. However, these opening switches or fuzes absorb considerable energy from the system and have been limited to voltage gradients of about 10^6 V/m. In addition, the relatively high resistance lasting for many microseconds prior to opening severely hampers compressed magnetic field generators, which is the usual way of generating very large pulsed currents.

The ideal opening switch would be a link of very low inductance and negligible resistance whose impedance could be raised to an unlimited value in a period of less than 1 μs by an external energy source at a prescribed time. Large area plane-wave detonation fronts in high explosives, produced by a technique developed at Sandia Laboratories, appeared to have application to this problem. We concluded that the most promising approach was to use a glass-lined plasma-filled cavity for the fusible link and close the cavity with high explosives. A secondary approach was to drive a foamed-metal link into the liquid vapor phase, as predicted by the Chart D hydrocode, and expand the liquid-vapor mixture into a ceramic cavity.

Procedure and Results

We conducted experiments with seven different plasma-filled cavity configurations. The cavities in Experiments 1-5 were rectangular parallelpipeds which were closed with plane-wave detonations. In Experiments 6 and 7, cylindrical cavities were

closed by imploding the glass walls. For the eighth experiment, a foamed metal conducting link mounted to ceramic plate was driven into the liquid-vapor phase with high explosives and expanded into a ceramic void. Figures 1-8 depict the setup for each experiment.

In each plasma experiment, the plasma was created by electrically exploding an array of 0.125 mm diameter tungsten wires with the electrical circuit shown in Figure 9. Current through the tungsten wires (Rs) rapidly heats the wires and raises the resistance of a single wire to about 125 Ω/m. This high resistance overdamps the circuit and reduces the current to a very low level. This period is known as the "pause" in exploding wire technology. After a few microseconds, a time proportional to the voltage gradient in the wire, the tungsten wires begin conducting along the surface of the wire, producing a plasma that rapidly expands and fills the cavity. The resistance of the cavity becomes very low, and the capacitor discharges through the low resistance to produce the traces shown in Figures 10 through 17. Peak currents in our experiments were usually about 1.5×10^5 A. Detonations were timed so that the cavity walls began moving inward at about the time of peak current. In a period of about one to a few microseconds (depending on cavity dimensions and wall velocity) the cavity would close, hopefully opening the circuit.

Cavity dimensions, predicted cavity closing times, voltage drops across the cavity at closing and ultimate voltage drops are included in Table I.

Discussions

In all experiments with plasma-filled cavities, we recorded voltage-time traces similar to those in Figures 18a or 18b. Our interpretation of these traces follows:

1. A voltage rise to Point A is associated with the reduction in cross section of the current-carrying

cavity. This point corresponds closely to the predicted time of closure of the cavity.

2. At or near closure, competing processes occur. Glass from the cavity wall mixes with and cools the plasma. At the same time the plasma/glass mixture is raised to high temperatures and pressures by the collision of the glass walls, each moving at 2-4 mm/μs. At these extreme pressures and temperatures materials normally considered nonconducting become poor to fair conductors, allowing the capacitor to continue discharging through a high resistance. It is significant that in all shots except No. 2, with wall velocities near 4 mm/μs, traces similar to that of Figure 18a were obtained while in Shot No. 2, with a wall velocity of about 2 mm/μs, we obtained the trace in Figure 18b.

3. Rarefaction from the outer surfaces cools the glass/plasma system, and the resistance rises (Point B).

4. The system finally finds a path for arc-discharge and discharges the capacitor (Point C).

Points A, B and C are marked on the voltage traces in Figures 11-17. Observations from each experiment are included below:

Experiment 1 (Figure 1). No voltage trace was obtained. The current trace in Figure 10 indicates that restrike occurred very soon after the detonation front reached the cavity wall which consisted of a single sheet of window glass. End electrodes were aluminum. When the thin glass wall moved inward enough to clear the end electrode, restrike through the explosion products could occur. To correct this problem, each cavity wall should be at least one-half of the cavity thickness and the end electrodes insulated.

Experiment 2 (Figure 2). Each cavity wall was glass >25 mm thick. The driver consisted of a 0.3 m diameter plane wave generator machined to the cavity dimensions, plus two each

25-mm-thick PBX 9404 charges (Figure 2). C-4 explosive was placed around the edge and tapered outward to prevent sharp discontinuities. As shown in Figure 11, we did interrupt the current but the extremely thick glass walls lowered the closing velocity and thus lengthened closing time.

Experiment 3 (Figure 3). In this experiment we used 12.5-mm-thick glass walls to decrease cavity closure time. To simplify the setup, the cavity was constructed in a phenolic sheet. Since the explosive charge extended well past the cavity, we did not machine the explosive. The voltage trace (Figure 12) indicates that the voltage increased predictably in time until cavity closure. At this point, discharge continued through a high resistance, which may be the phenolic sheet under explosive pressure.

Experiment 4 (Figure 4). Same cavity dimensions as in Experiment 3 but constructed with glass on all sides of the cavity (replacing the phenolic), and the explosive charge machined to the cavity dimensions. Results were similar to those obtained in Experiment 3 up to time of closure.

Experiment 5 (Figure 5). Due to concern over possible edge effects, the cavity for this experiment was widened from 50 mm to 200 mm. The cavity was also shortened to 50 mm in order to utilize explosive charges on hand. The voltage trace (Figure 14) is similar in shape to that of the previous experiment. Total voltage drop at the knee (Pt. A) is only about two-thirds that in Experiment 4. Since, however, the width was quadrupled and the length halved it would appear that the conductivity at closure was reduced. The system is too complex, however, to formulate rules for conductivity from these limited data.

Experiment 6 (Figure 6). We conducted this experiment and the next with cylindrical cavities, which have the advantage of zero edge effect. They suffer from the disadvantages of large travel distances for large cross sections, and the fact that

temperatures and pressures upon closure about a centerline are far greater than for plane collisions. Explosives are also more difficult to obtain in hollow cylindrical form than in flat sheets.

The voltage trace (Figure 15) is classic for our interpretation of this event. The voltage drop at the knee was disappointingly low; especially for the small (12-mm ID) cross section and 100-mm length. The low value, however, is consistent with the increased temperature and pressure expected for a cylinder collapsing about the centerline.

Experiment 7 (Figure 7). The purpose of this experiment was to obtain the advantages of a cylindrical configuration without the extreme plasma temperatures due to cylindrical collapse. We placed a porous fritted glass tube filled with sand on the centerline of the cavity, hypothesizing that the collapsing cavity wall would force the plasma through the tube into the sand-filled center. This should cool the plasma and open the circuit. The cavity wall then would collapse, not onto itself at the center, but upon a distended material removed from the centerline. The high pressure and temperature at collapse then would be avoided, at least for several microseconds.

The voltage trace (Figure 16) shows that this objective was partially achieved. Because the pore size in the fritted glass used for this experiment was too small for the flow rate needed, the pressure and temperature in the plasma were high, with a resulting increase in conductivity. Larger pore size or openings in the central tube are suggested.

Experiment 8 (Figure 8). In this experiment we cemented a distended aluminum link to an aluminum ceramic plate and placed the explosive charge on the other side. A Chart D hydrocode analysis predicted that the explosive shock wave transmitted through the ceramic plate would drive the distended aluminum into the liquid-vapor stage. The liquid-vapor phase aluminum,

still the current-carrying link, then would expand into a ceramic cavity. The ceramic backup plate, following behind the aluminum, should merge with the ceramic cavity and seal off the conducting path.

The current and voltage trace (Figure 17) show that an increased impedance was obtained. We offer no analysis of this event from the limited data on hand.

Conclusions

We were able to construct low-impedance plasma links in glass-lined cavities by exploding tungsten filaments in the cavities. These links provide relatively low impedance paths through which large currents can be carried for long periods of time. We were able to close the cavities at times independent of the current source with high explosives, thereby raising the impedance of the cavity and causing voltage drops that could be used for switching very large electric currents. Since the energy for switching was applied externally, no energy was absorbed from the circuit for the purpose of opening the switch. Also, since closure need not be effected until near peak current, the output of compressed magnetic field generators is not degraded.

Apparently at or near closure, competing processes limit the voltage drop across the switch. Further work to evaluate and reduce or control these processes is suggested. Also further work to evaluate quantitatively the conductivity vs. time of the switch should be conducted so that switches of other sizes and configurations can be designed for specific needs.

All plane wave detonations were initiated with single point initiated plane wave lenses. These lenses would be impractical for large switches. The mesh-initiation process developed at Sandia Laboratories would be applicable to large switches. Mesh initiation can also be applied to cylindrical devices.

TABLE I

CONFIGURATIONS AND RESULTS

Experiment No.	Cavity Dimensions (mm^2) Width	Length	Thickness	Predicted Closure Time (μs)	Voltage Drop (kV) Closure	Ultimate
1	100	150	25	2	Not Recorded	
2	100	150	25	4	22	64
3	50	100	25	2	38	41
4	50	100	25	2	33	61
5	200	50	25	2	23	148
	Diameter (mm) Cavity	Center Tube	Length			
6	12	0	100	1	19	97
7	50	15.8	100	2	21	175
	Distended Aluminum Link (mm) Width	Length	Thickness			
8	75	100	1.5	--	24	24

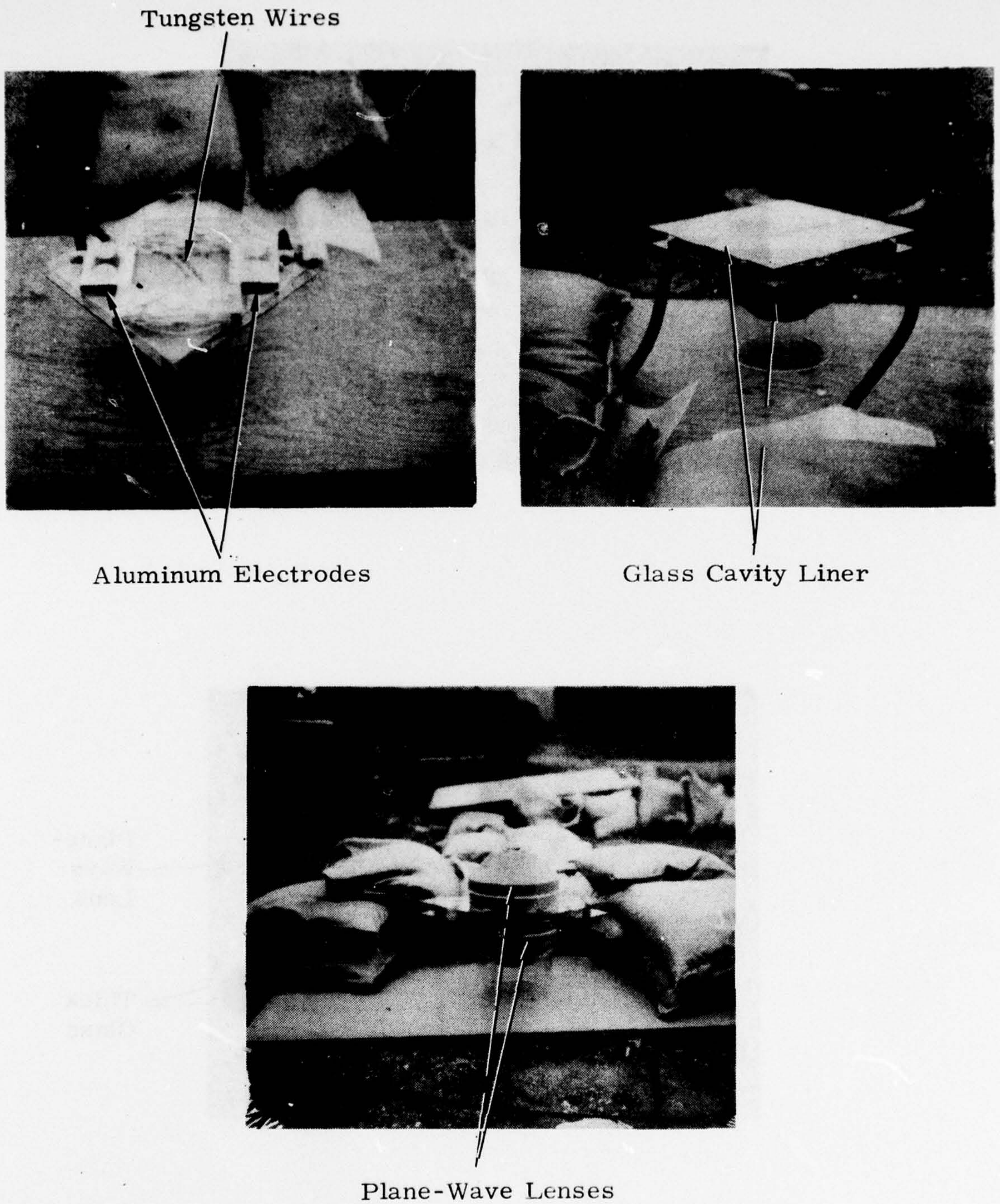
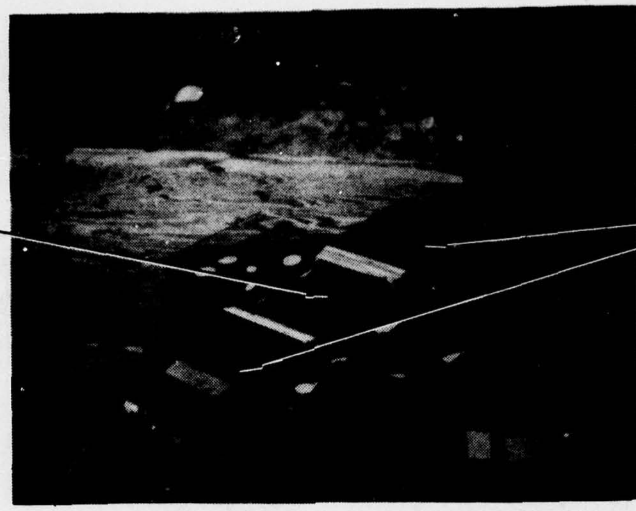


Figure 1. Setup Photographs for Experiment No. 1



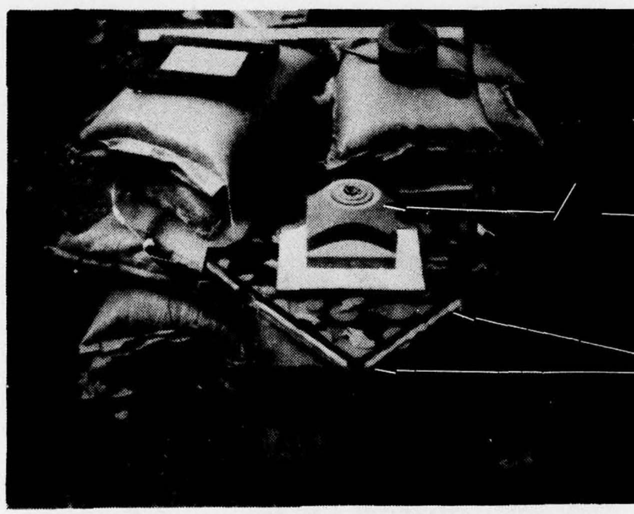
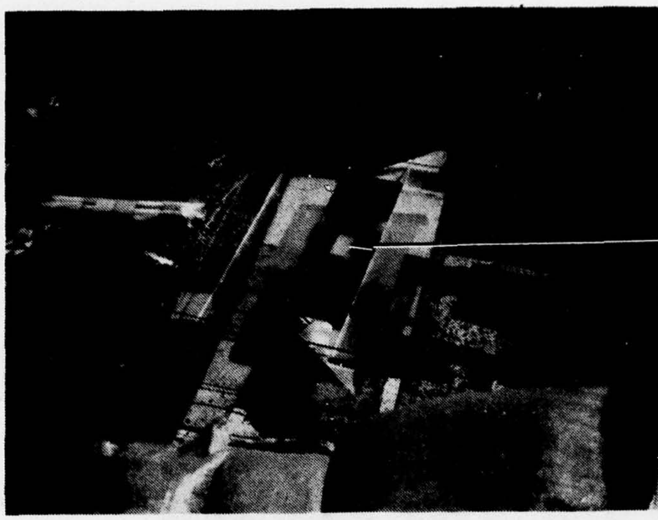


Figure 2. Setup Photographs for Experiment No. 2



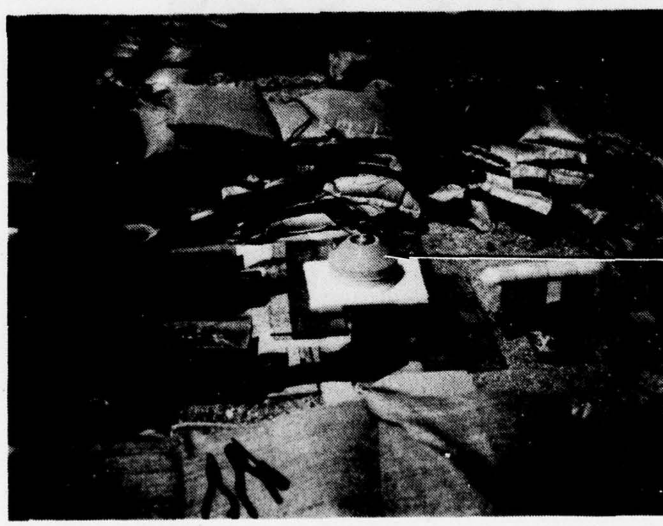


Figure 3. Setup Photographs for Experiment No. 3

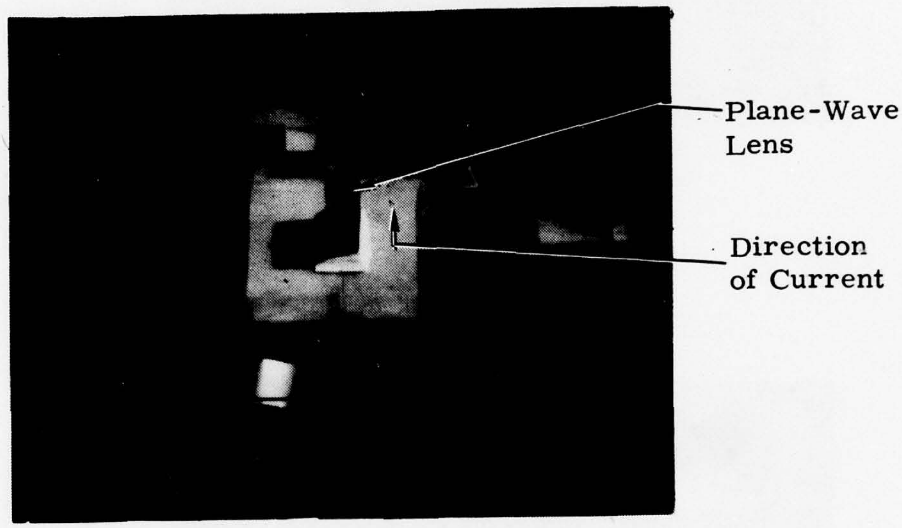


Figure 4. Setup Photograph for Experiment No. 4

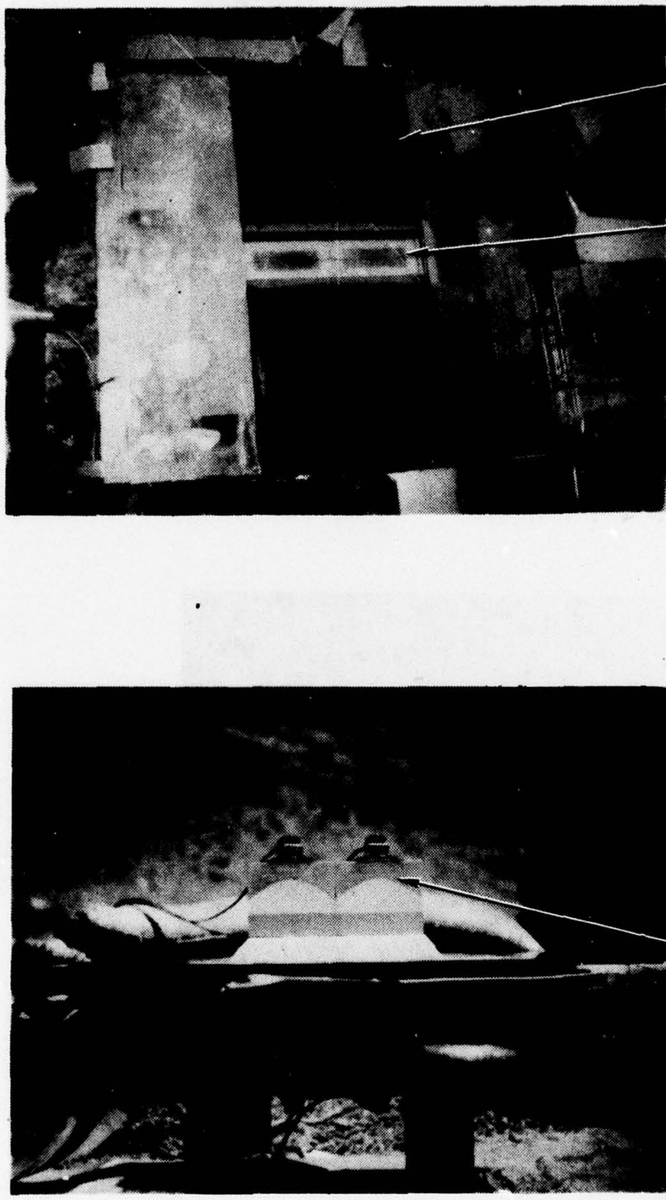
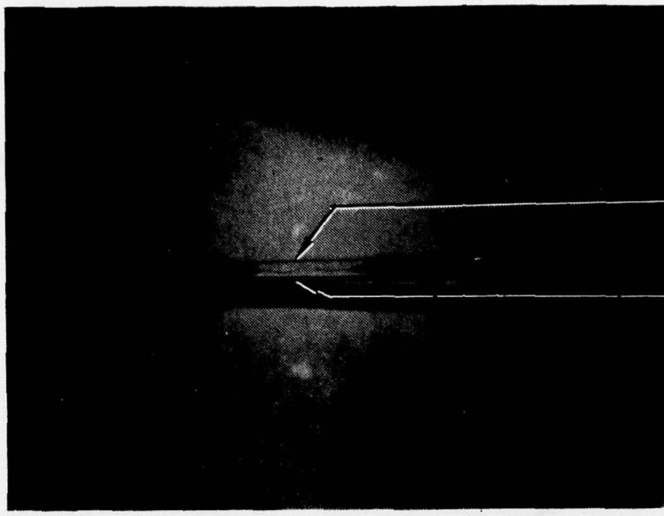


Figure 5. Setup Photographs for Experiment No. 5



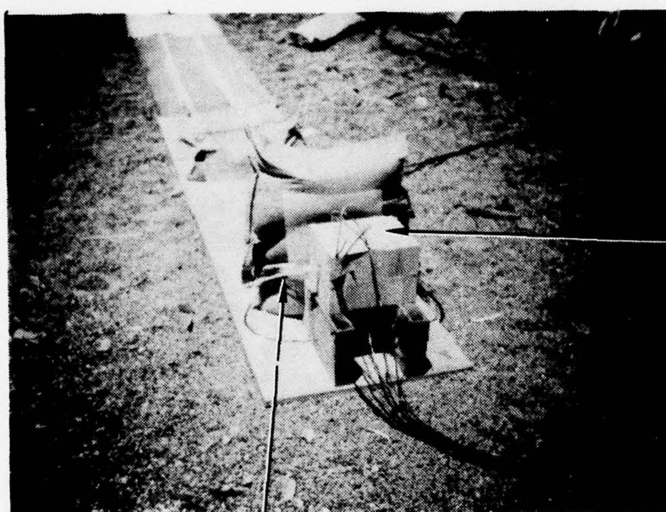


Figure 6. Setup Photographs for Experiment No. 6

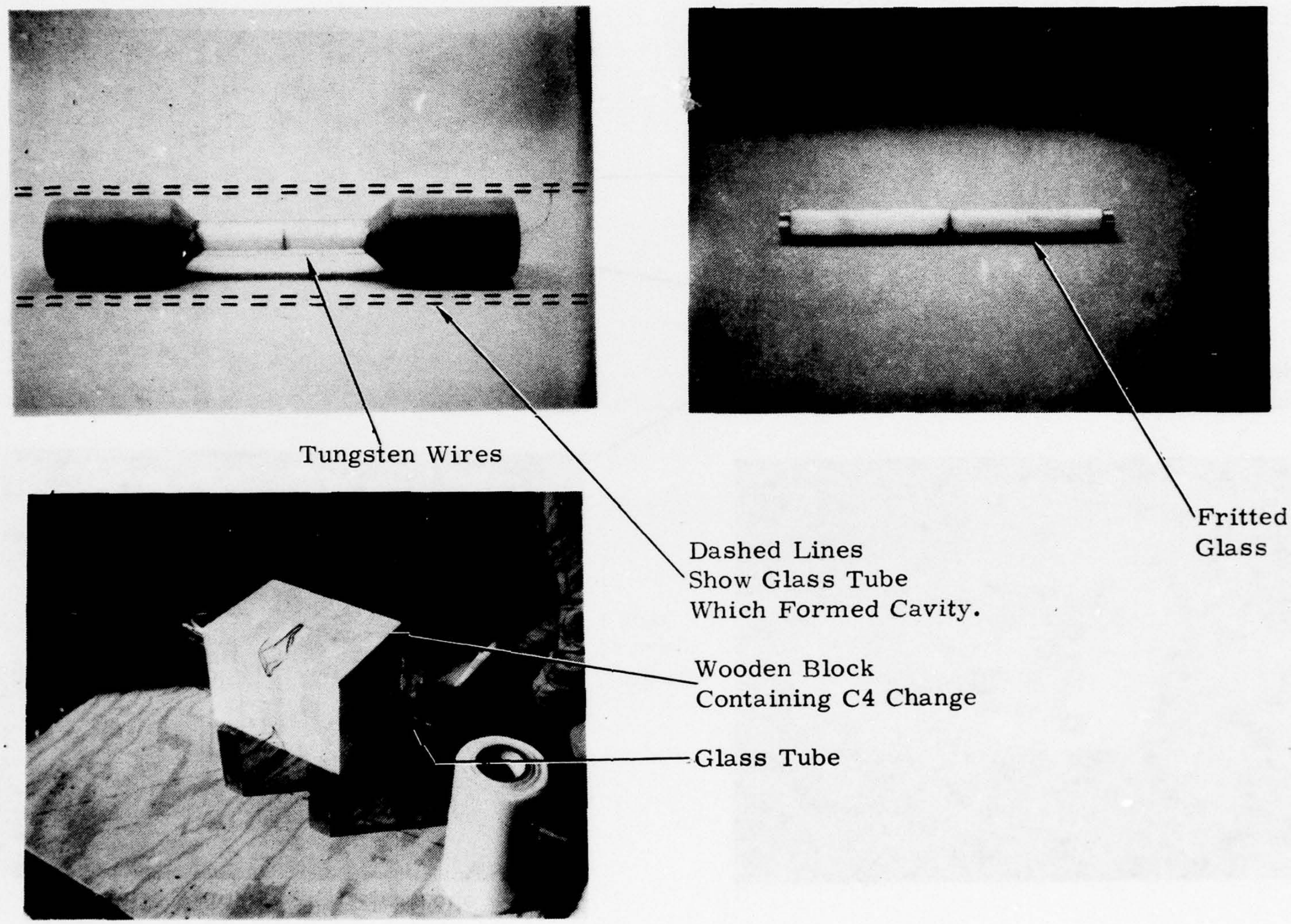


Figure 7. Setup Photographs for Experiment No. 7

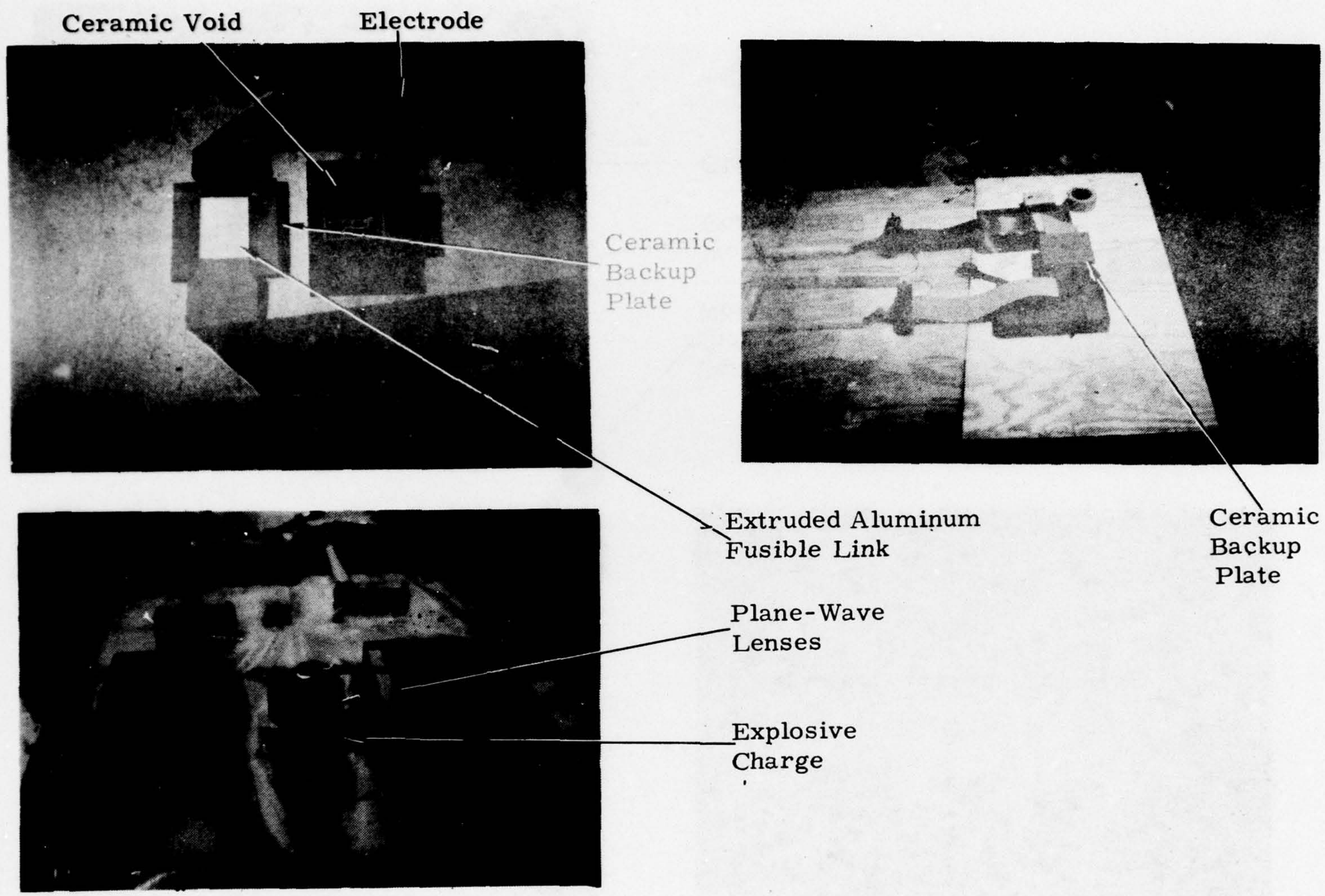
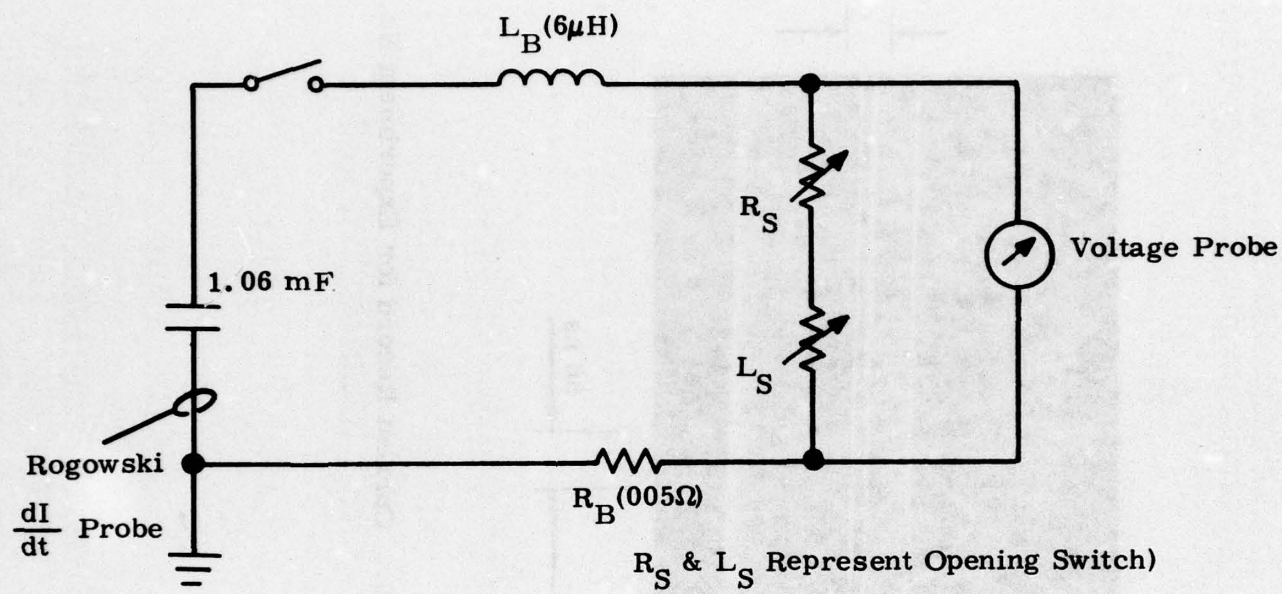


Figure 8. Setup Photographs for Experiment No. 8



R_S & L_S Represent Opening Switch)

Figure 9. Circuit for Opening Switch Experiments

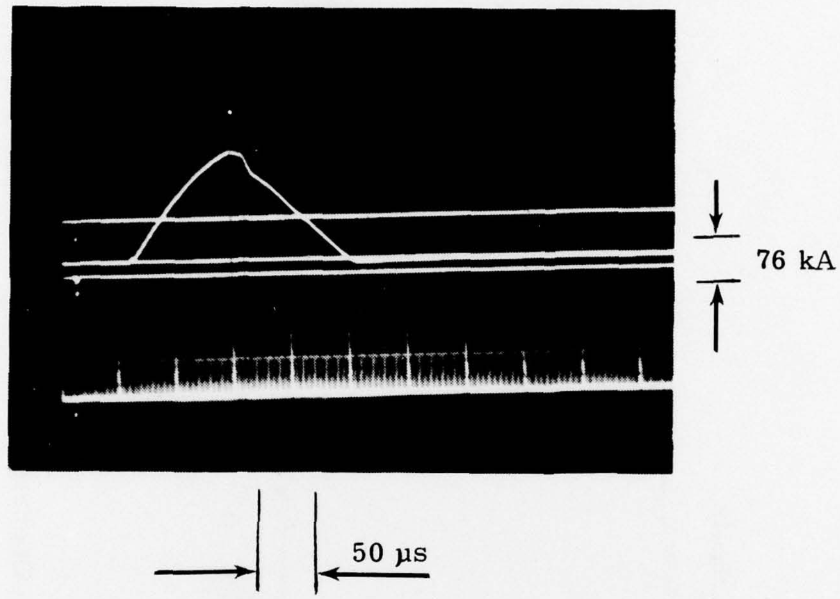


Figure 10. Current Record for Experiment No. 1

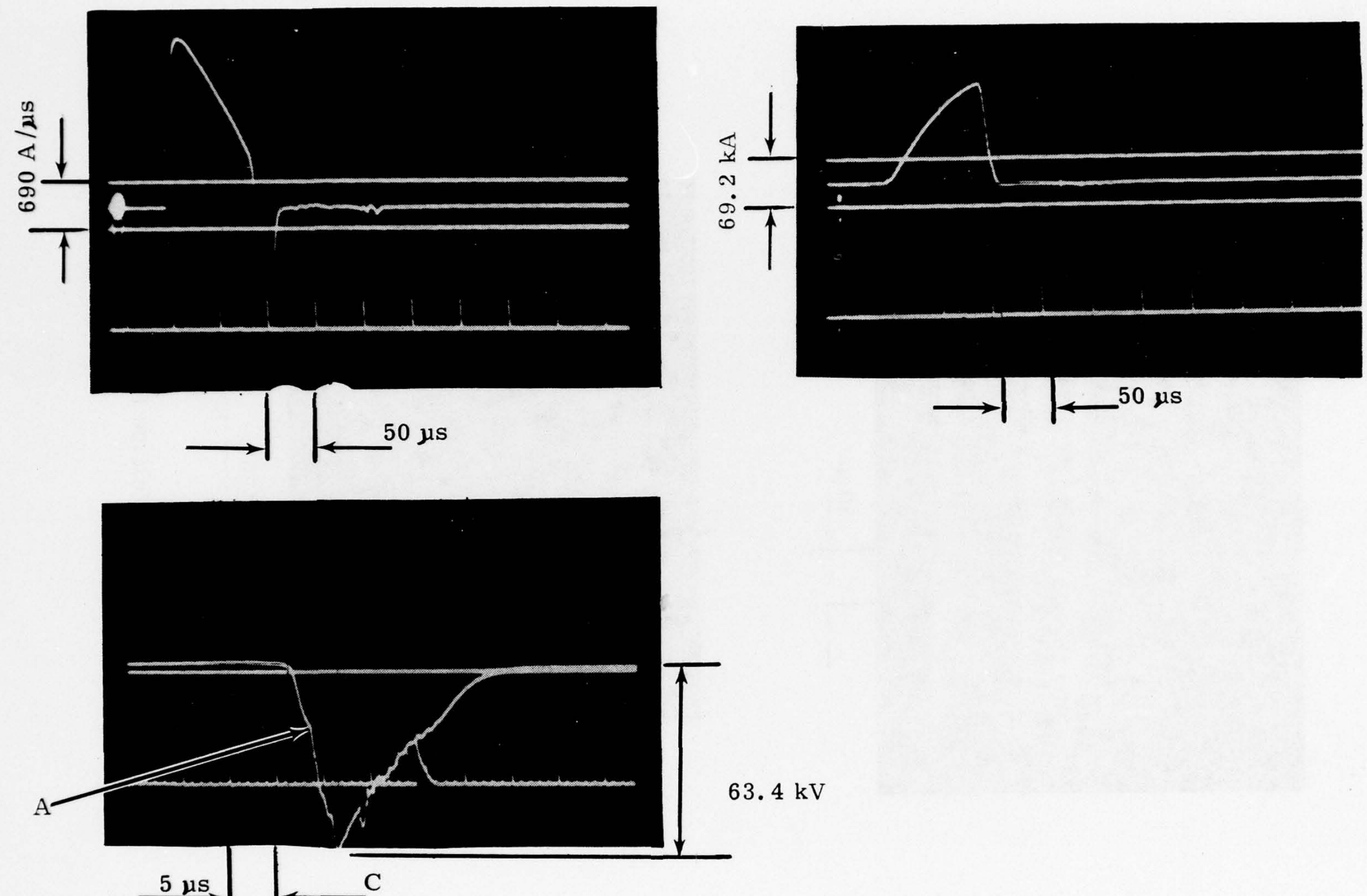
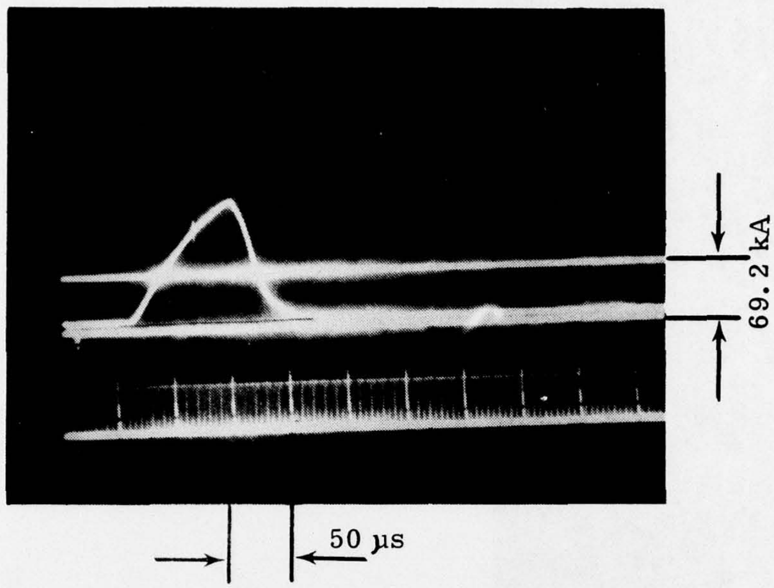


Figure 11. IDOT, Current and Voltage Records for Experiment No. 2



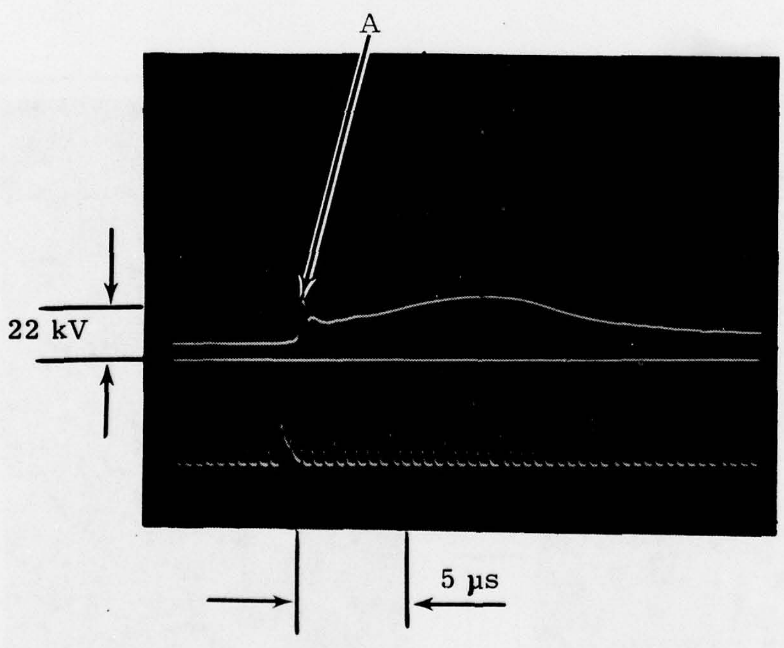


Figure 12. Current and Voltage Records for Experiment No. 3

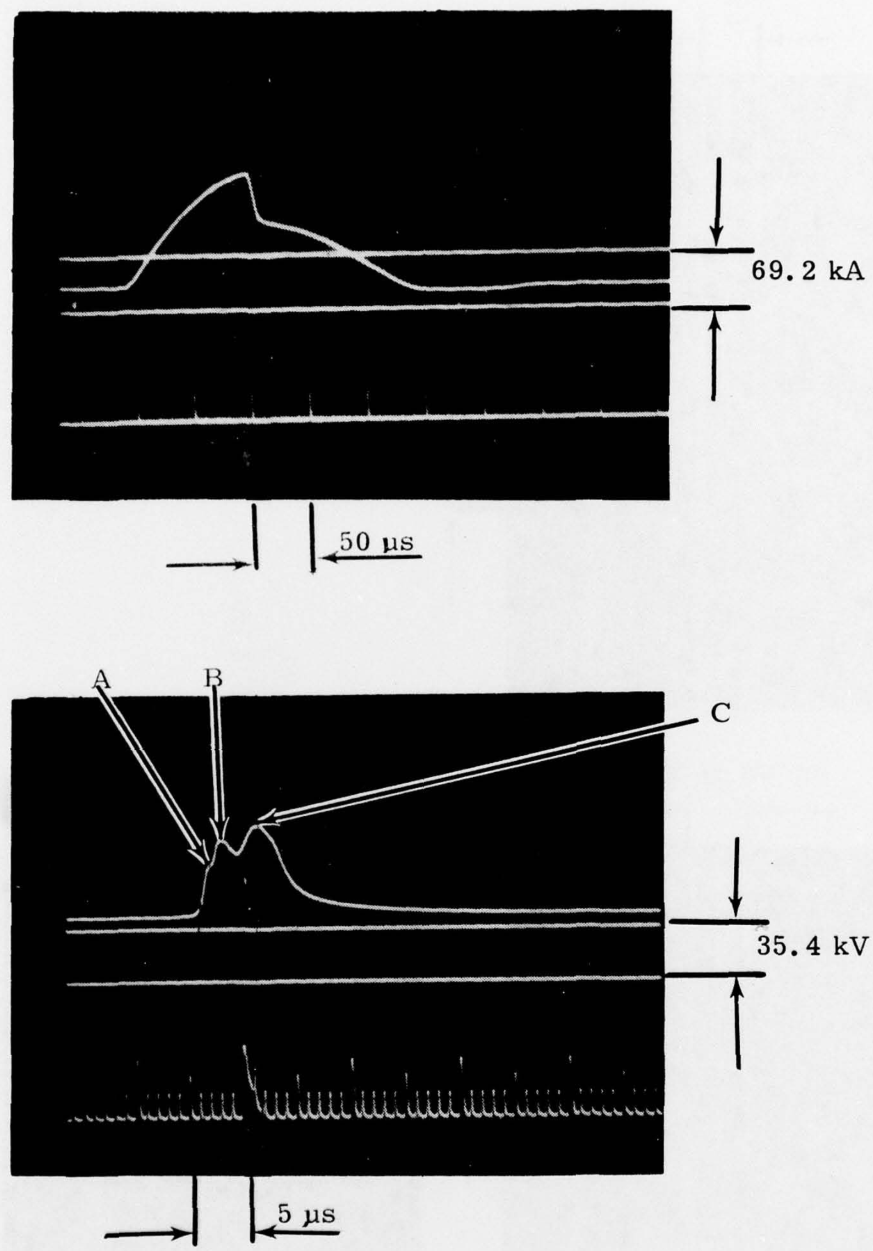


Figure 13. Current and Voltage Traces for Experiment No. 4

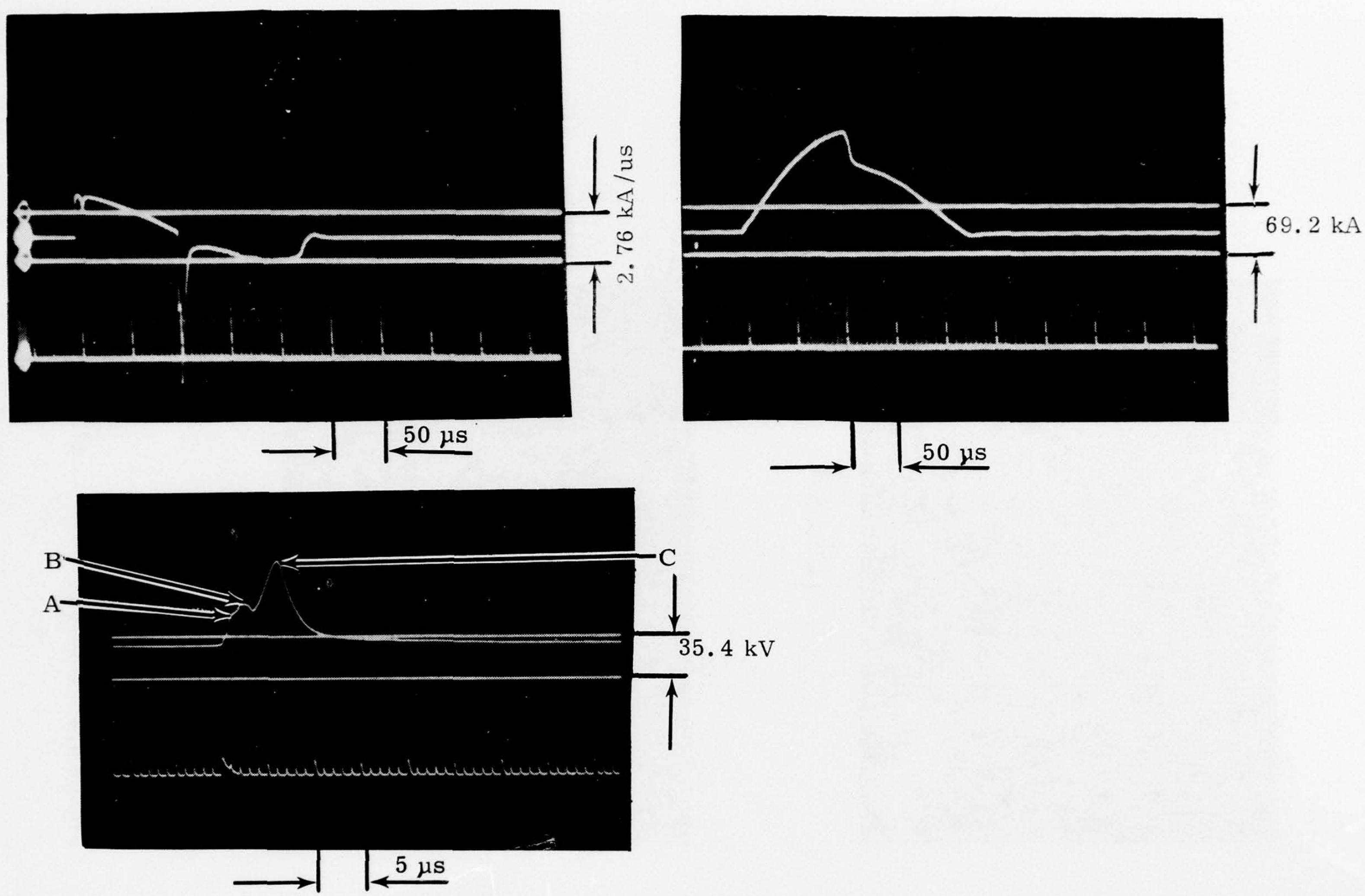


Figure 14. IDOT, Current & Voltage Records for Experiment No. 5

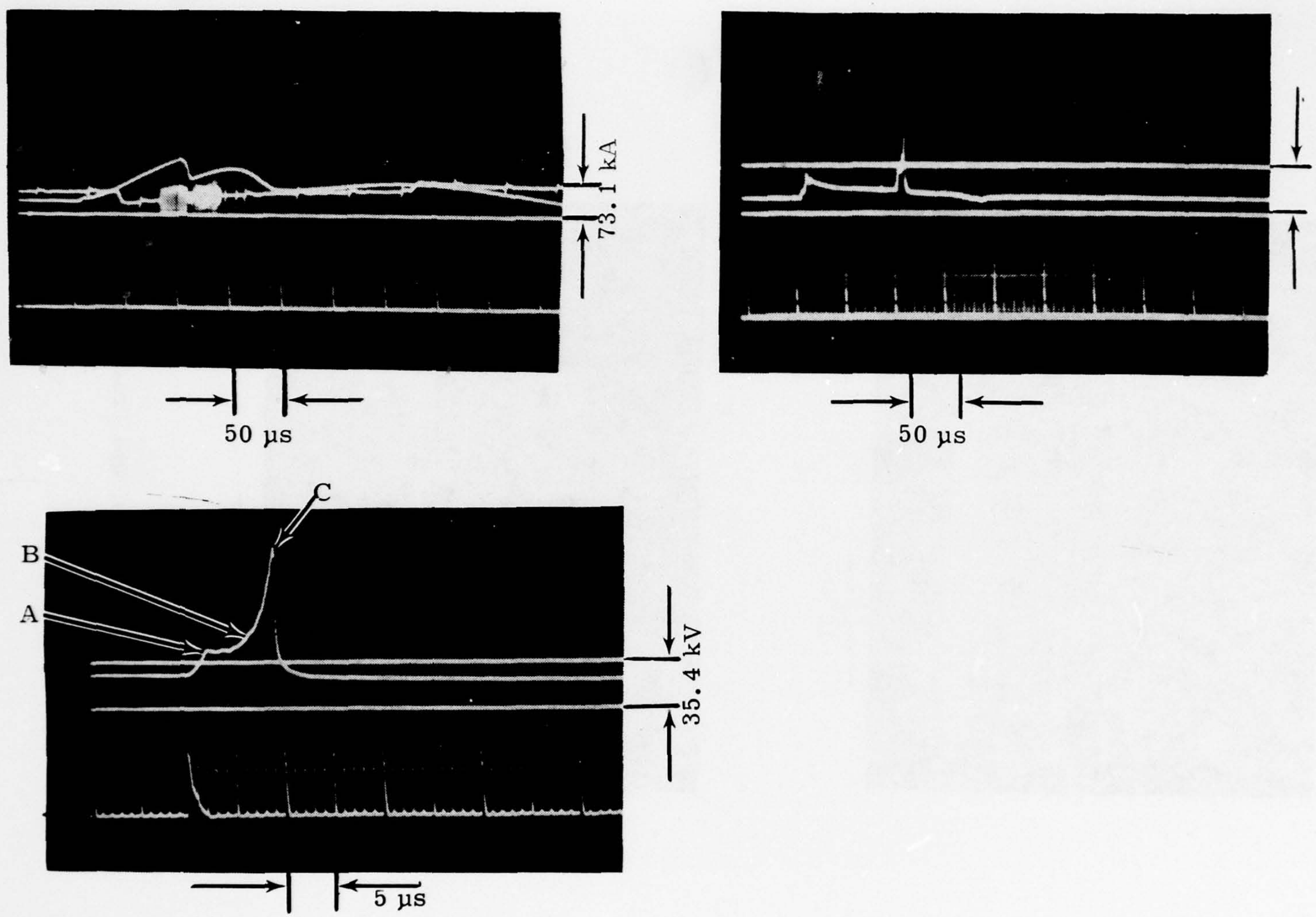
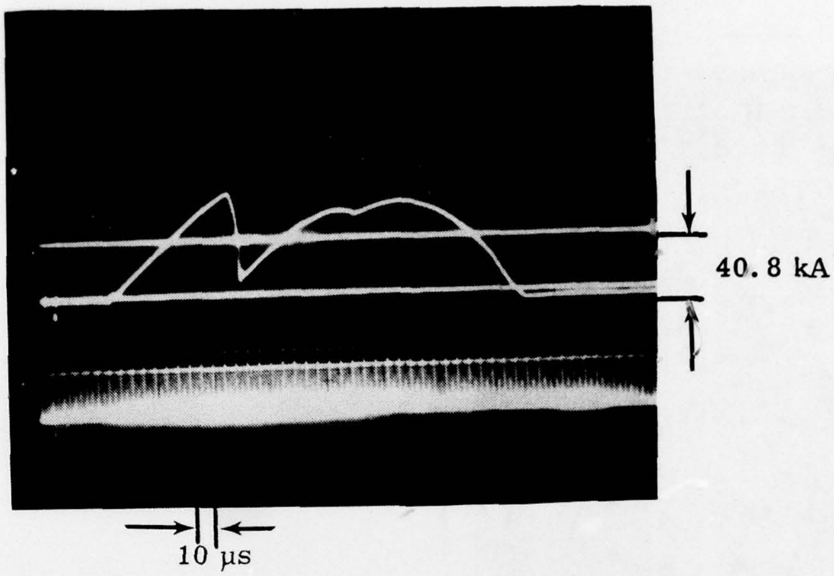


Figure 15. Current and Voltage Traces for Experiment No. 6



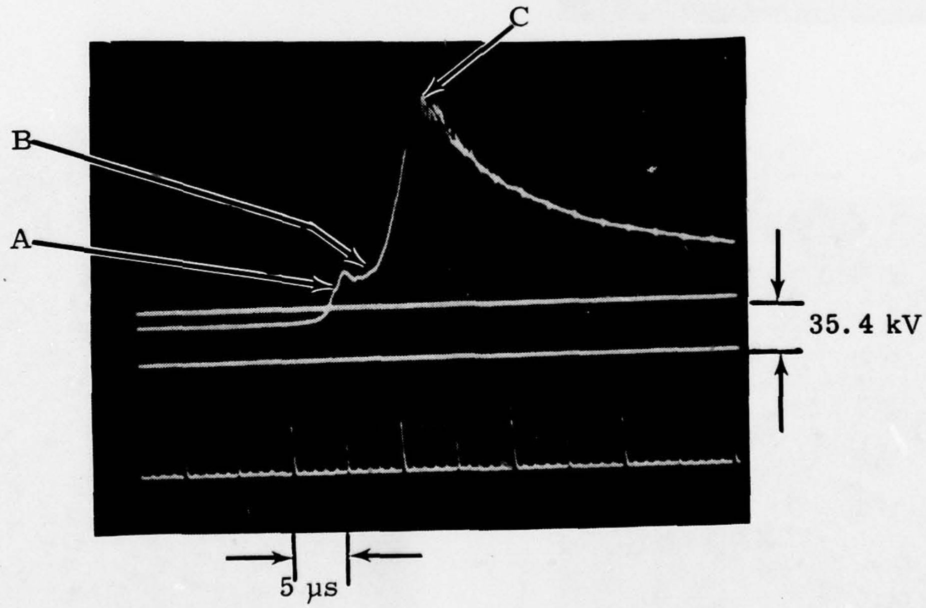


Figure 16. Current and Voltage Traces for Experiment No. 7

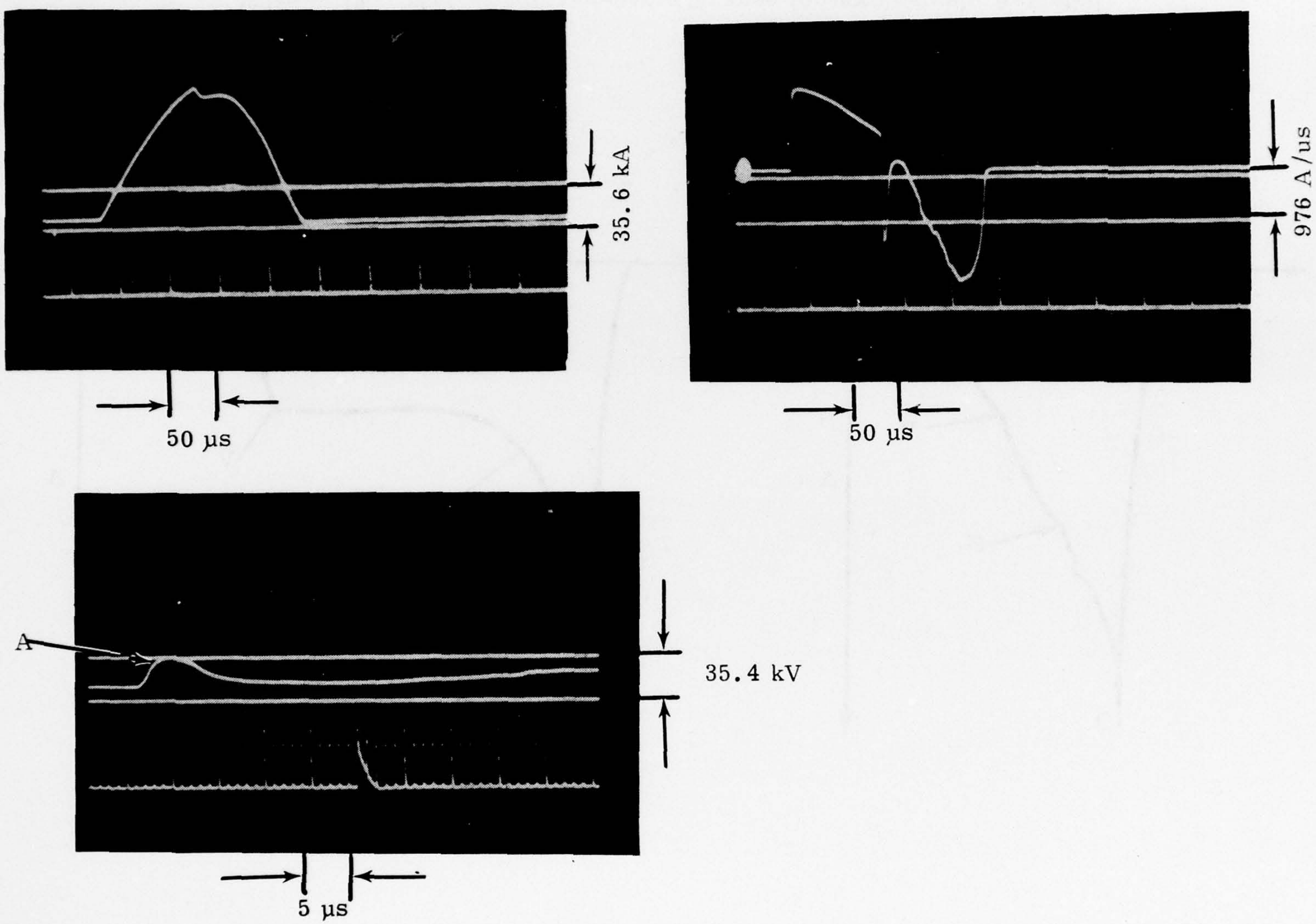
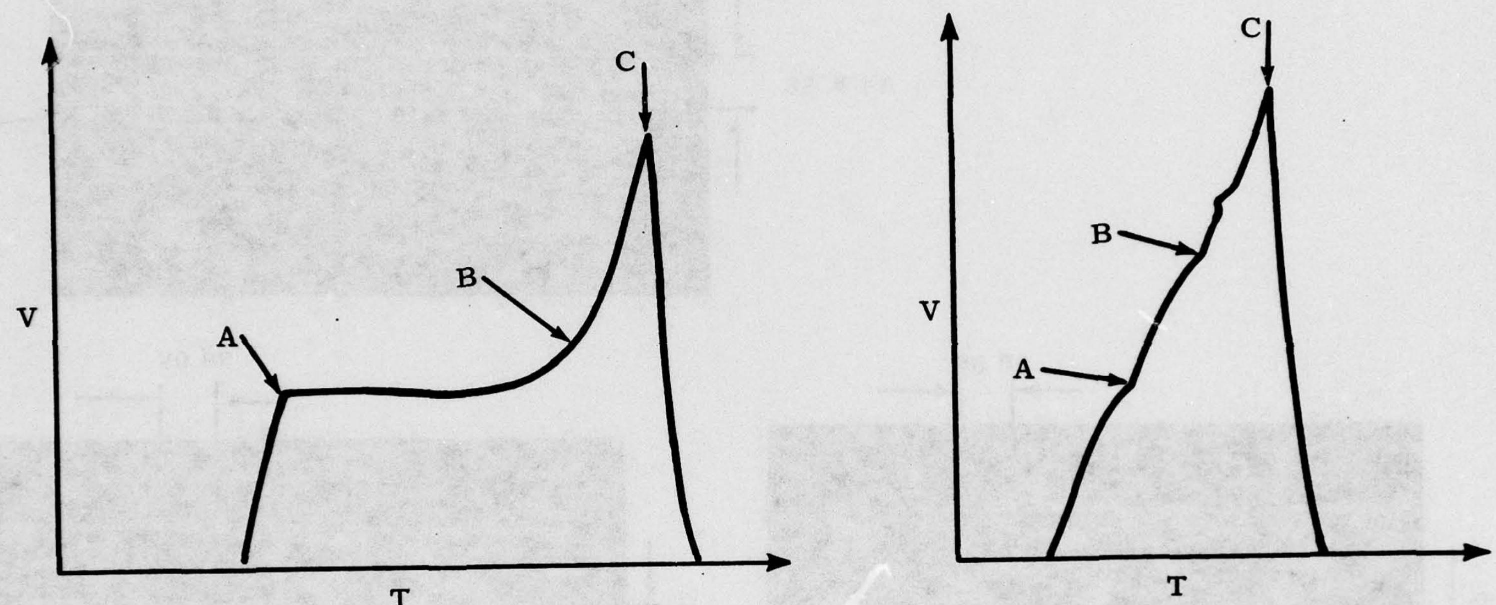


Figure 17. Current, IDOT and Voltage Traces Experiment No. 8



(a) Wall Velocity ≈ 4 mm/μs

(b) Wall Velocity ≈ 2 mm/μs

Figure 18. Typical Voltage-Time Traces for Explosively Actuated Fast Opening Switches

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